

Attorney Docket No. 84125  
Customer No. 23523

MINIATURE AXISYMMETRIC STREAMLINE TENSILE (MAST) SPECIMEN

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT PAUL V. CAVALLARO, employee of the United States Government, citizen of the United States of America, and resident of Raynham, County of Bristol, Commonwealth of Massachusetts, has invented certain new and useful improvements entitled as set forth above of which the following is a specification:

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1 Attorney Docket No. 84125

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3 MINIATURE AXISYMMETRIC STREAMLINE TENSILE (MAST) SPECIMEN  
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5 STATEMENT OF GOVERNMENT INTEREST

6 The invention described herein may be manufactured and used  
7 by or for the Government of the United States of America for  
8 Governmental purposes without the payment of any royalty thereon  
9 or therefor.  
10

11 BACKGROUND OF THE INVENTION

12 (1) Field Of The Invention

13 This invention relates to a miniature axisymmetric  
14 streamline tensile (MAST) specimen that is to undergo tensile  
15 stress. This MAST specimen is axisymmetrical with transition  
16 regions (i.e., regions that transition from the constant-  
17 diameter shoulder or grip regions near the end sections to the  
18 gauge section region) having variable curvature fillets and  
19 having a surface stress concentration factor (SSCF) close to  
20 unity.

21 (2) Description Of The Prior Art

22 The Navy has a need to test piezoelectric ceramic materials  
23 in order to determine their performance in sonar transducers.  
24 The piezoelectric ceramic materials are typically grown as a

1 single crystal which limits the size of the sample. These  
2 materials are very brittle and subject to cracking during use as  
3 a transducer. The Navy needs to know the useful life of these  
4 materials and the amount of stress that they can be subjected to  
5 while still being useful. It is also necessary to determine the  
6 electrical properties of the materials and how small flaws in  
7 the material affect these properties. No prior art test  
8 configuration properly gives this information for piezoelectric  
9 ceramics.

10 Tensile testing of ceramic materials using a standard  
11 tensile testing machine is not commonly performed because the  
12 tensile strength of ceramic materials is typically very  
13 sensitive to small cracks. These cracks are almost always  
14 present in normally sized specimens. In brittle materials, such  
15 as these ceramic materials, no energy is dissipated in plastic  
16 deformation ahead of the crack and the crack propagates easily.  
17 A bend test is more commonly used to determine the transverse  
18 rupture strength of a ceramic; however, this test does not give  
19 the true tensile strength of the material, and the ceramic is  
20 subject to failure at the points of load. Another problem is  
21 that properties determined using the bend test are not  
22 independent of the volume of material being tested.

1       The American Society for Testing and Materials (ASTM) is a  
2 large, not-for-profit, standards organization that provides a  
3 forum for producers, users, ultimate consumers, and those having  
4 a general interest to meet on common ground and write standards  
5 for materials, products, systems, and services. ASTM develops  
6 and publicizes voluntary consensus standards for materials,  
7 products, systems, and services. ASTM also publishes standard  
8 test methods, specifications, practices, guides,  
9 classifications, and terminology. ASTM's standards development  
10 activities encompass metals, paints, plastics, textiles,  
11 petroleum, construction, energy, the environment, consumer  
12 products, medical services and devices, computerized systems,  
13 electronics, and many other areas.

14       Several commonly used standardized tensile and compression  
15 specimen shapes can be found within the ASTM literature.  
16 Tension specimens are generally either flat or axisymmetric  
17 shaped. They are typically loaded for testing using wedge  
18 grips, collets, threaded ends or pinned ends. Typically, these  
19 existing specimen shapes are several inches or longer in length  
20 and include constant radius fillets that transition a grip  
21 region to a gauge section.

22       The use of constant curvature fillets, while reducing the  
23 complexity of specimen machining and costs, results in surface

1 stress concentration factors (SSCF) ranging minimally from 1.10  
2 to 1.20. A desired SSCF value is unity, 1.00. Furthermore,  
3 these specimens yield material strengths that are dependent upon  
4 specimen profiles.

5 With these specimens, the maximum stress may not occur  
6 within the gauge section where the applied stress field is  
7 assumed uniaxial. Rather, the maximum stress resides at a  
8 surface transition point where stress fields are neither  
9 uniaxial nor uniform, but rather biaxial and highly non-uniform.  
10 For materials that are brittle or lacking sufficient ductility,  
11 the surface transition points may become failure initiation  
12 regions, especially under dynamic fatigue loads. No suitable  
13 miniature axisymmetric standard tensile specimens were available  
14 that provide SSCFs close to unity.

15 The prior art discloses various testing specimens. One  
16 such prior art specimen is Van Winkle et al., U.S. Patent No.  
17 2,454,850, which is said to disclose a torsion specimen having a  
18 cylindrical gauge region.

19 Also known in the prior art is Scott et al., U.S. Patent  
20 No. 4,606,230, which is said to disclose a tensile testing  
21 apparatus with a tensile specimen having a rectangular gauge  
22 section.

1        Also known are Pratt, U.S. Patent No. 4,895,750, and Pratt,  
2 U.S. Patent No. 5,078,843, which are said to disclose a carbon  
3 composite tensile test specimen for high temperature testing and  
4 a method of fabricating the same. The tensile test specimen has  
5 a central gauge section that appears to be curved and of  
6 constant dimension.

7        Also known is Hiyoshi, U.S. Publication No. 2002/0166386  
8 A1, which is said to disclose a method and apparatus for  
9 measuring elongation in a contact-less manner capable of  
10 obtaining accurate measured value without attaching reference  
11 lines and capable of being automated wherein a test specimen has  
12 a straight, constant-width gauge section.

13       Also known is Oplinger et al., On the Streamline Specimen  
14 for Tension Testing of Composite Materials, Special Technical  
15 Testing Publication 864 - American Society for Testing and  
16 Materials, pp. 541-542, Philadelphia, 1985, which is said to  
17 disclose the analogy between elastic stress fields and 2-D fluid  
18 flow through a reducer. Concerning the testing of fibrous  
19 composites, this publication teaches the use of a flat,  
20 streamlined specimen to reduce surface stress concentration  
21 factors to near unity. Wedge grips are used to hold the flat  
22 sample in the test apparatus.

1 Other devices and specimens are known for tensile and  
2 compression testing of various materials. These specimens,  
3 along with those above, have various shortcomings including  
4 having maximum stress not occurring within a gauge section,  
5 failure regions at surface transition points and surface stress  
6 concentration factors (SSCF) not at unity. The shortcomings of  
7 these specimens are addressed by the present invention.

#### 8 9 SUMMARY OF THE INVENTION

10 A primary object of the present invention is to provide a  
11 miniature axisymmetric streamline tensile (MAST) specimen with a  
12 surface stress concentration factor (SSCF) close to unity, 1.0.

13 Another primary object of the present invention is to  
14 provide a MAST specimen with a surface profile consisting of  
15 variable curvature transition fillets and virtually stress  
16 concentration free surfaces compared to existing standardized  
17 specimens.

18 Another object of the present invention is to provide a  
19 MAST specimen with uniform axial stress fields within and  
20 adjacent to the gauge section unlike that of existing  
21 standardized specimens.

1 Another object of the present invention is to provide a  
2 MAST specimen with static and dynamic fatigue failure strengths  
3 which accurately reflect the material's true strength.

4 Another object of the present invention is to provide a  
5 MAST specimen which requires a smaller volume of material per  
6 specimen than existing standardized specimens.

7 Another object of the present invention is to provide a  
8 MAST specimen with lower material costs, machining costs and  
9 shipping and handling costs.

10 Accordingly, the present invention provides a MAST specimen  
11 having improved axisymmetric shaped design, variable curvature  
12 transition fillets, miniaturized profile dimension and shoulder  
13 region features used in conjunction with the collet loading  
14 method. An axisymmetric, rather than flat, design is preferred  
15 since no stress gradients exist in the hoop direction, i.e.,  
16 circumferential direction, of the specimen. The MAST specimen of  
17 the present invention is designed to permit various loading  
18 options.

19  
20 BRIEF DESCRIPTION OF THE DRAWING(S)

21 Reference is made to the accompanying drawings in which is  
22 shown an illustrative embodiment of the invention, from which  
23 its novel features and advantages will be apparent, wherein

1 corresponding reference characters indicate corresponding parts  
2 throughout the several views of the drawings and wherein:

3 FIG. 1 illustrates a perspective view of a MAST specimen  
4 profile of the present invention;

5 FIG. 2 illustrates a preferred variable curvature  
6 transition fillet of the MAST specimen of FIG. 1;

7 FIG. 3 illustrates a side view of a collet version of the  
8 MAST specimen of FIG. 1;

9 FIG. 4 illustrates a side view of a collet MAST specimen  
10 and hardware required for collet loading of a collet MAST  
11 specimen of FIG. 1;

12 FIG. 5 illustrates a side section view of threaded end  
13 loading of a threaded MAST specimen of FIG. 1; and

14 FIG. 6 illustrates a diagram of a test apparatus for  
15 piezoelectric specimens.

#### 16 17 DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

18 The present invention is a miniature axisymmetric  
19 streamline tensile (MAST) specimen 10 having improved  
20 axisymmetric surface profile design and surface stress  
21 concentration factor (SSCF) improvements, i.e., close to unity,  
22 1.0. The MAST specimen 10 of the present invention also has

1 improved variable curvature transition fillets 16, miniaturized  
2 profile dimension and shoulder 20 region features used in  
3 conjunction with the collet loading method. An axisymmetric,  
4 rather than flat, design is preferred since no stress gradients  
5 exist in the hoop direction, i.e., circumferential direction, of  
6 the specimen. The axisymmetric design requires shoulders 20  
7 because wedge grips cannot be applied to a curved surface.

8 A preferred MAST specimen 10 profile of the present  
9 invention is shown in FIG. 1. The MAST specimen 10 has two  
10 axisymmetric end sections 12 and a substantially central  
11 axisymmetric gauge section 14. A variable curvature transition  
12 fillet 16 provides a transition between each end section 12 and  
13 the substantially central gauge section 14. FIG. 2 shows a  
14 preferred first quadrant profile of a MAST specimen 10 showing a  
15 preferred variable curvature transition fillet 16. This  
16 transition fillet 16 can be calculated as a traction-free  
17 boundary with an offset distance. The offset distance provides  
18 improved handling characteristics. The offset is also used to  
19 create the same cross sectional area as other samples for  
20 comparison.

21 The MAST specimen 10 of the present invention is designed  
22 to permit various loading options. For example, the MAST  
23 specimen 10 may be loaded using collets, threaded ends, etc.

1 However, the collet method requires that the MAST specimen 10 be  
2 machined to include oversized load bearing shoulders 20 on each  
3 end section 12 to eliminate the possibility of a bearing stress-  
4 induced fracture within this load transfer region prior to  
5 failing the gauge section 14.

6 A collet version of the MAST specimen 10 is shown in FIG.  
7 3. A collet 22 is located near the free end of each end section  
8 12. A shoulder 20 provides a transition between each collet 22  
9 and each respective end section 12. The collet version 10' of  
10 the MAST specimen 10 must be sized to avoid bearing stress  
11 failures in the shoulder 20. For example, a collet-loaded MAST  
12 specimen 10' having a maximum SSCF of 1.01 and a length of 1.0  
13 inch will preferably have a resulting gauge section 14 diameter  
14 of 0.042 inch. Because this diameter is relatively small,  
15 extreme care must be used in installing the specimen within the  
16 test machine. Otherwise, MAST specimen breakage may occur  
17 during test set-up. However, any suitable length and gauge  
18 section 14 diameter may be used for the MAST specimen 10, 10'.

19 FIG. 4 shows the hardware required for collet loading.  
20 This test block hardware preferably includes an upper grip  
21 holder 50, a lower grip holder 52, an upper cover plate set 54  
22 and a lower cover plate set 56. Each cover plate set 54, 56  
23 preferably has annealed copper collets 58 and screws 60 for

1 fastening each cover plate set 54, 56 to the respective grip  
2 holder 50, 52. This collet loaded embodiment promotes alignment  
3 of the specimen with the direction of the load. The shoulders  
4 of the specimen act to center the specimen within collets 58..

5 Another preferred embodiment of the MAST specimen 10 is the  
6 threaded MAST specimen 10", shown in FIG. 5. In this  
7 embodiment, threaded regions 70 are formed, cut into or attached  
8 to each end of the specimen 10". The specimen 10" can then be  
9 mounted in test blocks 72 and 74 prior to testing. This  
10 embodiment affords a greater gauge section 14 diameter since  
11 threaded region 70 stress can be distributed over a larger  
12 surface area than found in the collet method.

13 In either embodiment, universal joints are recommended  
14 within the specimen-to-test machine load train to eliminate any  
15 misalignment effects on the specimen that could otherwise result  
16 in specimen breakage. For example, a threaded end MAST specimen  
17 10" having a maximum SSCF of 1.01 and a length of 1.0 inch will  
18 preferably have a resulting gauge section 14 diameter of  
19 approximately 0.080 inch, which is nearly double the gauge  
20 section 14 diameter of a preferred embodiment of a collet MAST  
21 specimen 10'. However, any suitable length and gauge section  
22 diameter may be used for the MAST specimen 10, 10".

1       An exemplary use of the MAST specimen 10 of the present  
2 invention is in the area of new generation piezoelectric  
3 materials such as Single Crystal PMN, i.e., Single Crystal Lead  
4 Magnesium Niobate. During testing, new generation piezoelectric  
5 materials, such as Single Crystal PMN, cannot be grown to the  
6 sizes required by most standardized tensile test specifications.  
7 Today, manufacturing methods for this material are limited to a  
8 maximum nominal size of only one inch. Therefore, to obtain  
9 accurate mechanical properties for the Single Crystal PMN that  
10 are ideally independent of both specimen size and profile, the  
11 MAST specimen of the present invention was developed with  
12 surface stress concentration factors (SSCF) approaching 1.0.  
13 This could only be accomplished by the MAST specimen 10  
14 containing variable curvature fillets 16 in transition regions.

15       Primary advantages of the MAST specimen 10 of the present  
16 invention include, but are not limited to, surface stress  
17 concentration factors (SSCF) close to unity, a surface profile  
18 consisting of variable curvature transition fillets 16,  
19 virtually stress concentration free surfaces compared to  
20 existing standardized specimens, uniform axial stress fields  
21 within and adjacent to the gauge section 14 unlike that of  
22 existing standardized specimens and static and dynamic fatigue  
23 failure strengths which accurately reflect a material's true

1 strength. The MAST specimen 10 also requires a smaller volume  
2 of material per specimen than existing standardized specimens.  
3 The MAST specimen 10 may be used for testing any suitable  
4 material including, but not limited to, metals, plastics and  
5 ceramics.

6 While the impetus of developing the MAST specimen 10 was to  
7 obtain a miniature specimen shape having substantial  
8 improvements over existing specimen designs found in the prior  
9 art, the MAST specimen 10 can be scaled for specimens regardless  
10 of size and loading methods. Additionally, the SSCF  
11 improvements also make the MAST specimen 10 a highly suitable  
12 specimen shape for compression testing of materials. However,  
13 from the compression perspective, the specimen diameters must be  
14 increased to avoid buckling failures prior to gauge section 14  
15 compression failures.

16 In order to prepare the MAST specimen 10, a single crystal  
17 sample of the material, such as a piezoelectric material, used  
18 for the test is grown. This crystal sample is then machined to  
19 the disclosed profile utilizing numerically controlled  
20 manufacturing. Preferably, the specimen 10 is cut down from the  
21 single crystal axially. This avoids radial scribing which can  
22 create surface stress concentrators. As an alternative, the  
23 specimen 10 can be made, i.e., machined, using a numerically

1 controlled lathe which will leave radial scribing such that the  
2 surface of the specimen has a surface stress concentration  
3 factor near unity. The radial scribing on the surface of the  
4 specimen can then be polished away. In either case, it is best  
5 that the numerically controlled machine follow the streamline  
6 equation with sufficient accuracy to avoid stress concentrators.  
7 This can be done by using point to point machining on a large  
8 set of points or by using a machine capable of following an  
9 equation precisely.

10 When a specimen is made from a piezoelectric material, it  
11 is desirable to monitor the specimen's electrical properties  
12 while it is being tested. FIG. 6 shows a test setup for this  
13 purpose. Electrical equipment 80 is electrically joined to each  
14 end section 12 of the specimen 10 such as by test blocks. The  
15 electrical equipment 80 should be capable of recording the  
16 voltage, current, impedance and resistance of the specimen 10  
17 while it is being tested.

18 The specimen 10 can be tested using a standard mechanical  
19 tensile test where the ends of the specimen are drawn apart from  
20 each other until the specimen breaks or the specimen can be  
21 loaded by providing an electrical difference voltage at each end  
22 of the specimen 10 causing it to contract. This can be  
23 performed by electrical equipment 80 attached to the test

1 blocks, which may apply an electrical current to the specimen  
2 cyclically to cause cyclical contractions. In either test, the  
3 specimen 10 can be cyclically loaded.

4 During testing, the specimen 10 may be subjected to axial  
5 forces, preferably performed mechanically, until failure. In a  
6 preferred embodiment, subjecting the specimens to axial forces  
7 until failure comprises causing contraction of the specimen by  
8 providing an electrical current to the specimen. The elongation  
9 of the specimen, the axial forces on the specimen, and the  
10 electrical properties of the specimen may be measured during  
11 testing. After the specimen destructively fails, it is  
12 microscopically examined to find the flaw causing the failure.  
13 Other properties measured from the specimen are stress, strain,  
14 cycle life, power output and acceptable flaw size.

15 The exemplary embodiments herein disclosed are not intended  
16 to be exhaustive or to unnecessarily limit the scope of the  
17 invention. The exemplary embodiments were chosen and described  
18 in order to explain the principles of the present invention so  
19 that others skilled in the art may practice the invention. As  
20 will be apparent to one skilled in the art, various  
21 modifications can be made within the scope of the aforesaid  
22 description. Such modifications being within the ability of one

1 skilled in the art form a part of the present invention and are  
2 embraced by the appended claims.